Confidential Business Information is marked by brackets and italicized text: "*[text]*".

Date Submitted: [June 10th 2019]
Clarifications Submitted:

Air Liquide Hydrogen Energy U.S. LLC.

Location of Headquarters: Houston, TX, USA
Location of Biofuel Production Facility: Application is for a specific pathway for Biogas to Liquid Hydrogen.
Air Liquide production facilities (owned & operated by Air Liquide):

- Conley, GA (biogas production facility) - "Live Oak"
- Walnut, MS (biogas production facility) - "NEML"
- + Future Biogas production facilities in development
- *[Clark County, Nevada]* (Hydrogen Liquefaction facility) - "West Coast RLH2"

Fuel Pathway Requested

Fuel Type	Feedstock	Production Process Technology	RIN D-Code Requested
Liquid Hydrogen	**Biogas** from landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated MSW digesters	Steam Methane Reforming (SMR) & Hydrogen Liquefaction	3

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A. Technical Justification

1. Fuel Pathway Description

Air Liquide petitions the Agency under the Renewable Fuels Standard (RFS) program to generate D3 RINs (cellulosic) for renewable liquid hydrogen (RLH2) made from waste-derived biogas. Air Liquide’s biogas-to-RLH2 process uses waste-derived biogas from landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated MSW digesters to produce hydrogen by:

1. Upgrading the collected biogas to renewable natural gas via membrane separation
2. Injecting renewable natural gas into a commercial distribution system (common carrier pipeline)
3. Taking equal quantity of gas from a common carrier pipeline connected to a hydrogen production unit (steam methane reformer or “SMR”). The SMR process uses electricity along with steam to produce synthesis gas (“syngas”) which is then purified to fuel cell quality hydrogen via pressure swing adsorption (PSA).
4. Liquefying, storing, transporting, and delivering the Renewable Liquid Hydrogen via Cryogenic Trailer to hydrogen refueling stations (HRS).
5. Dispensing renewable hydrogen at the HRS for use in hydrogen fuel cell electric vehicles (HFCEVs), using either cryogenic pumps or regasification & compression to compress the hydrogen up to 700 bars in the HFCEV Hydrogen tank(s).

EPA previously evaluated biogas production from landfills in the final rule published on March 26, 2010 (75 FR 14760) (the “March 2010 RFS rule”) and modeled in more detail the suite of biogas from landfills, separated MSW digesters, wastewater treatment digesters, agricultural digesters, and other waste digesters (“waste-derived biogas”) as a feedstock for biofuel production in the final rule published on July 18, 2014 (79 FR 42128) (the “July 2014 RFS rule”), which are identified under pathway Q.

Today the SMR process is widely used for the production of hydrogen for industrial applications. By replacing the fossil natural gas feed in the SMR process with renewable natural gas (RNG) from upgraded waste-derived biogas, the process produces a renewable hydrogen product. This renewable hydrogen produced at the SMR plant is then liquefied, stored, and transported via cryogenic trailers to hydrogen fueling stations (HRS). At the HRS, the RLH2 is pumped to 700 bars and dispensed to HFCEVs. For this specific pathway application, the Air Liquide RLH2 plant will be located in *[*(b) (4) [redacted]*]*, and the RLH2 will be supplied to the Hydrogen Fueling Stations for HFCEVs on the US West Coast.

Press release:
https://www.airliquide.com/media/air-liquide-build-first-world-scale-liquid-hydrogen-production-plant-dedicated-supply-hydrogen-energy-markets

2. Process Flow Charts

[[redacted]]

[redacted]

3. Comparison to Previously Evaluated Pathways

EPA currently has not approved pathways for renewable hydrogen generation in the RFS program. Following the announcement of Air Liquide’s West Coast RLH2 project, Air Liquide has decided to apply for a specific pathway in addition to its previous petitions for generic Biogas-to-hydrogen pathways, submitted on 09/02/2016. This proposed biogas-to-RLH2 pathway can be compared to pathway ‘Q’ under the current RFS program, which defines renewable liquefied natural gas (LNG) from feedstock which includes biogas from landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated MSW digesters; and biogas from the cellulosic components of biomass processed in other waste digesters (eCFR §80.1426 Table 1)[1]. This pathway currently generates D3 RINs. This proposed biogas-to-RLH2 pathway utilizes the same feedstock and further processes the renewable natural gas into renewable liquid hydrogen through steam methane reforming and cryogenic liquefaction.

Similarities with renewable liquefied natural gas pathways also exist in feedstock accounting mechanisms and tracking/record keeping of renewable natural gas from the point of injection into the commercial distribution system to where the fuel is dispensed at the fueling station for use in HFCEVs. In the West Coast RLH2 Project, the renewable natural gas from the biogas upgrading plant is nominated for delivery to the SMR plant. Once the renewable natural gas is processed into hydrogen ($CH_4 + 2H_2O \rightarrow CO_2 + 4 H_2$), the product is liquefied and transported by cryogenic trailers to the hydrogen refueling station.

The renewable hydrogen dispensed at the hydrogen refueling station corresponds to the relative amount of renewable natural gas used to produce the fuel. The amount of renewable natural gas injected into the commercial distribution system is tracked and reported along with the amount of fuel dispensed at the hydrogen fueling station to ensure correct allocation and renewable classification. This tracking and reporting mechanism is similar to that which is practiced in the renewable CNG/LNG pathways and would be subject to comparable record keeping as defined in §80.1454 (k)(1).

Similar rules around RIN generation, as defined in eCFR §80.1426(f)(11)(ii) for the renewable CNG/LNG pathway, will also apply to the proposed biogas-to-RLH2 pathway. Among these, it will be ensured that renewable natural gas used to produce renewable hydrogen will only generate RINs for the corresponding amount of hydrogen fuel dispensed to the transportation market. No other party will rely on the volume of biogas/CNG/LNG for the creation of RINs. Additional rules for RIN generation will apply as well, and will be comparable to those of the renewable CNG/LNG pathway.

The proposed biogas-to-RLH2 pathway would also be subject to similar registration requirements under the RFS program as defined in §80.1450(b)(1)(v)(D), which applies to facilities producing other renewable fuel from biogas.

Comparable to the renewable CNG/LNG pathway, a mass-balance approach is proposed for the production of renewable hydrogen at the SMR. In this approach, the amount of renewable natural gas injected into the natural gas transportation system at the biogas upgrading plant corresponds to an equal amount of natural gas withdrawn from the pipeline at the SMR plant that is processed into a relative amount of renewable hydrogen for use in HFCEVs.

In addition to the above comparisons in the current RFS program, the California Low Carbon Fuel Standards (LCFS) has identified 11 hydrogen pathways, including five that utilize steam methane reforming as the primary production process. Variances in the pathways include onsite vs. centralized reforming, hydrogen compression vs. liquefaction, and use of fossil natural gas vs. renewable feedstocks.

4. Commercial Viability

Production of hydrogen via steam methane reforming using renewable natural gas (RNG) as feedstock is one of the most economical processes currently available to produce renewable hydrogen. Cryogenic Liquefaction represents the most economical way to store and transport hydrogen given the current level of development of the HFCEV market. Steam methane reforming is the most widely-used and efficient process for hydrogen production, supplying 95% of today’s hydrogen.

5. Renewable Fuel Production Volumes (Historic and Projected)

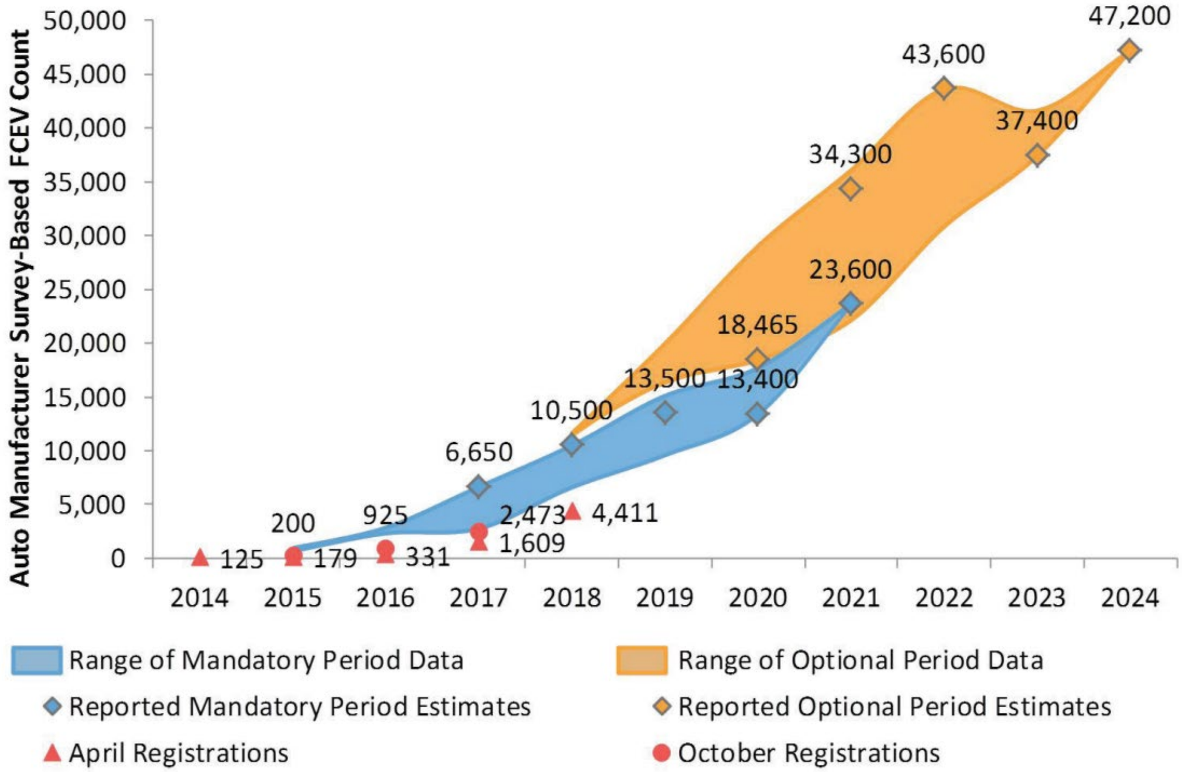
Air Liquide has not yet produced renewable hydrogen under the proposed biogas-to-RLH2 pathway. However, Air Liquide has extensive experience in producing both renewable natural gas, as well as gaseous and liquid hydrogen.

The two facilities of reference are the *[*(b) (4) [redacted]

Furthermore, Air Liquide is committed to advancing the “Hydrogen Economy” globally, with special focus on mobility applications. The company has already invested or has planned investment in hydrogen refueling infrastructure in California, the northeast United States, and other countries (France, Germany, Japan, Denmark). To date, more than 75 hydrogen fueling stations have been designed and installed by Air Liquide worldwide.

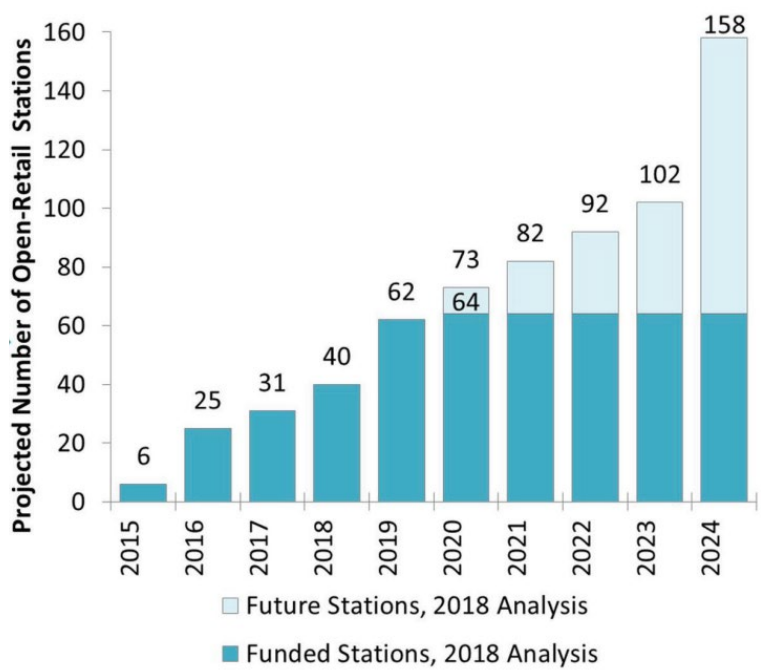
The state of California leads the way in hydrogen infrastructure development and vehicle adoption. As shown in Figure 6, the California Air Resources Board (ARB) predicts that California HFCEV fleet will grow to 10,500 by the end of 2018 and 23,600 by the end of 2021, representing a total demand of approximately 15 Metric Tonnes per day of clean hydrogen. *[*(b) (4) [redacted]*.]*

Figure 6: *Current and Projected On-Road FCEV Populations*



Source: “2018 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development”, CARB

Figure 7: *Cumulative Existing, Funded, and Projected Publicly Funded Station Counts*



Source: “2018 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development”, CARB

Along with the growth of the hydrogen mobility market in California, additional growth is projected for the northeastern region of the United States. This growth is driven by a collaboration between Air Liquide and Toyota Motor Sales USA to build twelve hydrogen refueling stations in the northeast U.S.

B. Organization Information

1. Organization Description

Air Liquide is the world leader in gases, technologies and services for Industry and Health. Air Liquide is present in 80 countries with more than 65,000 employees and serves more than two million customers and patients. Oxygen, nitrogen and hydrogen have been at the core of the company’s activities since its creation in 1902.

Air Liquide Advanced Technologies (ALAT) specializes in gas engineering and cryogenics and operates in business sectors as varied and specialized as Aeronautics, Space, Marine, Scientific Research, Hydrogen energy, but also Chemicals and Pharmaceuticals, Electronics and Optoelectronics. Air Liquide is actively involved in developing the hydrogen energy industry at global level. The Group has delivered more than 75 hydrogen stations worldwide. Air Liquide already operates hydrogen filling stations for the general public in Europe, including Rotterdam, Netherlands and Düsseldorf, Germany. In Germany, Air Liquide is also a partner of the “H2 Mobility initiative” which aims to deploy about 400 hydrogen stations covering the whole country by 2023. In 2014, the Group announced the installation of four new hydrogen filling stations in Denmark.

Air Liquide Advanced Technologies U.S. LLC is the U.S. division of ALAT that includes the Biogas and Hydrogen Energy businesses. In 2014, Air Liquide announced plans to develop and supply a fully-integrated hydrogen fueling infrastructure in the northeast United States, in collaboration with Toyota Motor Sales USA, Inc. (Toyota), to support Toyota’s introduction of a new hydrogen fuel cell electric vehicle (HFCEV), the “Mirai”, and its plans to deliver hydrogen FCEVs in the United States. Air Liquide’s U.S. hydrogen fueling infrastructure in the northeast will initially consist of twelve filling stations across a number of states, with plans to extend the network as demand warrants. In 2018, Air Liquide announced its 150 million dollar commitment to the RLH2 project on the US West Coast in order to scale up the development of HFCEV.

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C. Fuel Type

1. Technical Description

Hydrogen is used as fuel in hydrogen fuel cell electric vehicles (HFCEV) which produce zero CO_2 emissions at the tailpipe. A number of automotive manufacturers have already developed or are in the process of developing HFCEV models, including Toyota, Hyundai, Mercedes-Benz, BMW, and Honda. These vehicles use a Proton Exchange Membrane (PEM) fuel cell to convert gaseous hydrogen and oxygen into electric energy and water. The vehicle's hydrogen tank holds approximately 5 kg (11 lb) of hydrogen, which will power the vehicle for around 300 miles.

Hydrogen can be used to power light/medium duty vehicles, but also in larger vehicles such as buses, heavy duty trucks, and smaller applications such as bikes, scooters, and forklifts.

2. Information for New Fuel Types

i. Chemical Composition

The hydrogen diatomic molecule consists of two hydrogen atoms (H_2). The lower heating value of hydrogen is 120.21 MJ/kg (51,682 Btu (LHV)/lb)[2] .

ii. Regulatory Definition Justification

Renewable liquid hydrogen produced via steam methane reforming using renewable natural gas upgraded from waste-derived biogas is expected to qualify for D3 RINs given the cellulosic classification of the feedstock, waste-derived biogas.

iii. Equivalence Value Application

The standard EV calculation is designed for an internal combustion (IC) engine. As such, it does not adequately reflect the different drivetrain of HFCEVs. Therefore, **Air Liquide proposes an adjusted equivalence value (EV) for the biogas-to-hydrogen pathway, where 0.58 lb (0.263 kg) H_2 represents one gallon of renewable fuel with an EV of 1.0.** This value is obtained using the standard calculation for EV and an EER multiplier term of 2.5 to adjust for higher fuel economy in light/medium duty HFCEVs. The approach is similar to that of the California Air Resources Board (CARB).

An "Energy Economy Ratio" (EER) is a dimensionless value that represents the efficiency of a fuel used in a powertrain as compared to a reference fuel. EERs are typically a comparison of miles per gasoline gallon equivalent (mpge) between two fuels. CARB has defined EER terms in the state's Low Carbon Fuel

Standards (LCFS) for a number of alternative fuels, as shown in the table below. For light/medium duty hydrogen fuel cell vehicles, the EER value relative to gasoline is 2.5.

Table 1: EER Values for Fuels Used in Light- and Medium-Duty, and Heavy-Duty Applications

Light/Medium-Duty Applications (Fuels used as gasoline replacement)		***Heavy-Duty/Off-Road Applications (Fuels used as diesel replacement)***	
Fuel/Vehicle Combination	***EER Values Relative to Gasoline***	***Fuel/Vehicle Combination***	***EER Values Relative to Diesel***
Gasoline (incl. E6 and E10) or E85 (and other ethanol blends)	1.0	Diesel fuel or Biomass-based diesel blends	1.0
CNG/ICEV	1.0	CNG or LNG (Spark-Ignition Engines) CNG or LNG (Compression-Ignition Engines)	0.9 1.0
Electricity/BEV, or PHEV	3.4	Electricity/BEV, or PHEV* Truck Electricity/BEV or PHEV* Bus Electricity/Fixed Guideway, Heavy Rail Electricity/Fixed Guideway, Light Rail Electricity/Trolley Bus, Cable Car, Street Car Electricity Forklifts	2.7 4.2 4.6 3.3 3.1 3.8
H2/FCV	2.5	H2/FCV H2 Fuel Cell Forklifts	1.9 2.1

*BEV = battery electric vehicle, PHEV= plug-in hybrid electric vehicle, FCV = fuel cell vehicle, ICEV = internal combustion engine vehicle.

Source: *http://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf*

As seen in Table 1, EER values for gasoline, diesel, and CNG/LNG vehicles are 1.0. Subsequently, the EVs that have been calculated for these fuels and their replacement renewable fuels under eCFR §80.1415 would remain unchanged by the proposed use of the EER multiplier term.

Along with adequately reflecting the different drivetrain of HFCEVs, the adjusted EV will help to encourage renewable hydrogen production from renewable natural gas. In the proposed biogas-to-RLH2 pathway, the feedstock (renewable natural gas) for the final process (steam methane reforming) is a feedstock only needing compression or liquefaction to become a renewable fuel (CNG/LNG) defined under the Renewable Fuel Standard (RFS). In the absence of an EER multiplier, hydrogen producers cannot compete with the CNG/LNG pathway in the sourcing of Renewable Natural Gas. Additionally, calculating EV based only on energy content ignores the greatest advantage of HFCEV: that vehicles with this drivetrain go a much farther distance on the same amount of energy than a typical Internal Combustion engine vehicle.

This advantage is factored in with the EER approach and accounts for the equivalent displacement of gasoline vehicles on the road.

To reflect the different drive train of hydrogen fuel cell vehicles and overcome the disadvantage of producing renewable hydrogen over renewable natural gas from the same feedstock, Air Liquide proposes to use the EER value of 2.5 as a multiplier in the EV equation for the biogas-to-hydrogen pathway. This would result in 0.58 lbs (.263 kg) of H_2 representing one gallon of renewable fuel with an EV of 1.0. The 0.58 value is obtained by back-calculating from an EV of 1.0 with the 2.5 EER term included the original equation. The lower heating value (LHV) of 51,682 BTU is used to represent the energy content of H_2.[2]

$$EV = (.58\ lb\ H_2)\ \left(\frac{1}{0.972}\right) \times \left(\frac{51{,}682\ BTU\ (LHV)}{77{,}000}\right) \times (2.5) = 1.0$$

iv. Fuel Registration

It is not necessary for a hydrogen producer to register under 40 CFR Part 79 because hydrogen is considered an alternative fuel.

There are, however, published hydrogen fuel quality standards which would apply to the biogas-to-hydrogen pathway. SAE International has published hydrogen fuel quality standards (J2719) for commercial proton exchange membrane (PEM) fuel cell vehicles. The purpose of this hydrogen fuel quality standard is to specify hydrogen fuel quality requirements for all commercial hydrogen fueling stations for PEM fuel cell vehicles (FCVs). Hydrogen quality is defined as the quality measured at the dispenser nozzle using a suitable adapter and methodology developed by the ASTM D03 (Gaseous Fuels) Committee.[4]

3. Other Relevant Information

N/A

D. Production Process

1. Process Overview

Air Liquide's biogas-to-RLH2 process utilizes waste-derived biogas to produce liquid hydrogen by: 1) upgrading the collected biogas to RNG via membrane separation 2) injecting and transporting RNG via commercial distribution system (pipeline) to SMR plant 3) feeding the nominated RNG to a SMR process that uses steam to produce syngas which is then purified to fuel cell quality hydrogen via PSA, and 4) liquefying hydrogen using a cryogenic processing plant

Steam Methane Reforming is widely used today for the production of hydrogen. Syngas production is the process of reacting/combusting a hydrocarbon stream to form hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), and water (H_2O). Light hydrocarbons such as natural gas and Refinery Fuel Gas (RFG) and butane are typically used to produce hydrogen. Natural gas and RFG principally consist of methane, ethane, propane, butane, and small quantities of heavy hydrocarbon (C5+), carbon dioxide, nitrogen and sulfur. In Air Liquide's proposed pathway, some or all of the hydrocarbon feed will be substituted with RNG produced from upgraded waste-derived biogas. The SMR process itself remains unchanged.

Steam Methane Reforming is a catalytic reaction between a hydrocarbon and steam to produce syngas. The hydrocarbon and steam reaction require heat; therefore, a furnace with burners is required for the reaction to take place. The high temperature syngas effluent stream from the reformer furnace is cooled, producing steam. The cooled syngas stream flows to the shift reactor to produce additional hydrogen and carbon dioxide from any carbon monoxide present in the syngas effluent. The shift reactor effluent is further cooled to condense unreacted steam, allowing it to be recovered for reuse. After the water has been removed, the syngas is purified into hydrogen in a Pressure Swing Adsorption (PSA) unit, with the impurities rejected by the PSA (primarily carbon monoxide, carbon dioxide, and unreacted hydrocarbon feeds) and sent to the furnace as fuel.

Feed and Fuel Stream Handling

[(b) (4) [redacted]].

Feed Pretreatment

[(b) (4) [redacted]

Reforming

[(b) (4) [redacted]

[redacted] [redacted]

[redacted] [redacted]

[redacted]

Shift Conversion

[(b) (4) [redacted]

[redacted] [redacted]

Process Gas Cooling

[(b) (4) [redacted]

Hydrogen Purification

[(b) (4) [redacted]

[redacted]

[redacted].

(b) (4) [redacted]*.]*

Hydrogen Liquefaction:

[(b) (4) [redacted]

[redacted] *(CBI)*

(b) (4) [redacted]

[(b) (4) [redacted]*.]*

Hydrogen dispensing at Hydrogen refueling stations:

[(b) (4) [redacted]*.]*

2. Mass and Energy Balances

See attachments. (b) (4) [redacted] **]*

3. Historical Process Data

N/A - The Project is planned for start-up in *[*(b) (4) [redacted]*]*.

4. Information for New Production Processes

[(b) (4) [redacted]

[redacted]

(b) (4) [redacted]

Air Liquide

[redacted]

5. Other Relevant Information

N/A

E. Feedstock

1. Type of Feedstock

Feedstock is that of Pathway ‘Q’: “Biogas from landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated MSW digesters; and biogas from the cellulosic components of biomass processed in other waste digesters.”

2. Information for New Feedstocks

N/A

3. Other Relevant Information

N/A

F. Coproducts

1. Technical Description

N/A

2. Market Value

N/A

3. Coproducts Used as Livestock Feed

N/A

G. Attachments

1. Mass and Energy Balance: Biogas-to-Liquid Hydrogen Pathway

H. References

[1] Electronic Code of Federal Regulations. <http://www.ecfr.gov/>.

[2] Lower and Higher Heating Values of Fuels. Hydrogen Analysis Resource Center.<http://hydrogen.pnl.gov/tools/lower-and-higher-heating-values-fuels>.

[3] 2015 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. California Air Resources Board. <http://www.arb.ca.gov/msprog/zevprog/ab8/ab8_report_2015.pdf>.

[4] Hydrogen Fuel Quality for Fuel Cell Vehicles. SAE International. <http://standards.sae.org/j2719_201109/>.